Art. XIX.—*A Description of a New Pendulum Apparatus, with Half-Seconds Pendulums.*

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When the Kater's Invariable Pendulums, lent by the Royal Society of London for the Gravity Survey of Australia initiated by this Society, arrived and were installed at the Observatory, the cumbrous character of the whole apparatus convinced me that the cost of transport and of installation at the various observing stations would be a serious hindrance to the undertaking. When, therefore, some months later, an Austrian officer of the warship *Saida* brought a set of half-seconds pendulums, for making a series of gravity observations at the Observatory for connection with the Vienna base, I was struck with the immense convenience of transport and facility in making the necessary observations which these instruments afforded, and as I soon ascertained that the results appeared in every respect as good as with the larger pendulums, I determined to get a set made to test the question, hoping that they might be found efficient for the survey work. These pendulums and apparatus are now complete, and are on the table for the inspection of members. They are made after the plan adopted by Colonel von Sterneck of Vienna, but with certain modifications, and are in some respects similiar to the half-seconds pendulums recently used in the United States Coast and Geodetic Survey, and described by Mendenhall in his report for 1891.

The apparatus consists of three half-seconds pendulums, a coincidence or flash apparatus, a pendulum-stand, thermometers, air-pump, &c., as well as a break circuit chronometer.

In the design and construction of the pendulums, the chief and essential requirement of invariability and symmetry of form have had the first consideration. Great care was also taken as regards the metal of which they were first formed, to secure

solidity, evenness of texture and a good surface. The form is simple, and, with the exception of the cross-heads, are figures of revolution. It has been usual to have the knife-edge on which the pendulum oscillates on the pendulum itself, but it is almost impossible in that case to secure invariability of length, owing to gradual blunting of the knife-edges by wear; they are therefore made part of the stand, while the planes are on the pendulum cross-head; by this means, wearing of the knife-edges or sharpening them brings about no variation in the lengths of the pendulums.

Of the pendulums themselves, two are made from phosphor bronze, and one from ordinary gun-metal, and care was taken that the metal is solid and homogeneous throughout. In shape they are all alike, the "bob" or "weight" of the pendulum is in the form of two low truncated cones, base to base in one solid casting 98mms. diameter at base of cones, and 36mm. thick; the rod is truly cylindrical, 1cm. diameter, the length of pendulum over all 303mm., and from planes to bottom of bobs 235mms. The rod is fixed to the bob by being turned down at one end to a very long cone, which nearly fitted a hole in the bob of a similar conicity; the rod was then ground into the hole until it fitted nearly up to a small shoulder at the top of the conical part of the rod. The bob was now immersed in boiling water to expand it, when the rod was inserted and driven up to the shoulder; in cooling, the bob and rod became to all intents and purposes solidly connected. The lower end of the rod projected slightly through the bob, while the bottom of the hole through the bob was slightly countersunk; the projecting rod was here carefully rivetted, and the bottom of the bob then finished off.

The suspensions are agate planes attached to metal cross-heads, which are made to fit accurately and symetrically on the rods, great care being taken to secure as perfect rectangularity of the agate planes with the pendulum rod as possible. The suspension cross-heads consist of cubes of gun-metal truly bored to fit on the pendulum rods. The lower part of the cubes are widened out on two sides to give a bearing for the planes as well as to form two cylindrical arms, by which the pendulums are lifted and lowered on to the knife edges of the stand. On the two faces of the cube that are not widened out are fixed two small mirrors of parallel

glass, silvered at the back. The agate planes are fitted into a separate piece of gun-metal by means of a groove planed out on one face with V's at the sides; the agates are ground to a bevelled edge on two sides to fit into this groove, and are driven in tight in such a way as to be free from any strain that would crack or splinter them. The agate planes thus fitted are then ground and polished as one plane. The agates and their matrix of gun-metal fit precisely on planes at the bottoms of the cross-heads, and are secured by four small steel screws. Now, as it is absolutely necessary the agate planes should be accurately at right angles to the pendulum rods, they had to be carefully tested, for no matter how accurate may be the workmanship in fitting the cross-heads, some small errors are sure to remain. To do this I arranged a spectrometer with a piece of metal exactly the size of the pendulum rod, fixed horizontally, on which to place the cross-head and agates, then illuminating the slit of the collimator, read the angle of reflection from one of the planes in both horizontal and vertical direction with the telescope. The cross-head was then reversed 180° till the other plane came under the collimator, and the angles read again; any difference of angles was got rid of by lightly scraping the bottom surface of the cross-head on which the agate plate rested. By this means the agate planes were brought practically at right angles with the rods in both directions. Great care was also taken in securing the cross-heads to the rods. They fitted sufficiently tight to enable swings to be taken for ascertaining their times of vibration, and when this was satisfactory, a hole was bored through cube and rod and a conical steel pin driven firmly through both. The top of the rod and cross-head were then finished off together, and the pendulums were thus completed. Every part had been well smoothed and highly polished previously to the final fixing of the cross-head. The weights of the pendulums are approximately as follows:—No. I., 1814 grammes; No. II., 1787 grammes; No. III., 1811 grammes. Arrangements are made to avoid the necessity of handling or touching the pendulums, except with a leather-lined lifting handle and a leather strap, by which they can be lifted from their chamois-lined couches in the packing case, and placed on the lowering forks of the stand without touching any part with the fingers. To preserve their invariability, all touching

that might cause corrosion, oxidation, or usage likely to cause abrasion, has to be most carefully avoided.

There are two stands: one which is exhibited is the vacuum stand or receiver, in which the pendulums are swung in vacuo or at any atmospheric pressure below the normal; it is a hollow cone of gun-metal with a wide base, and formed with a flange at the top to receive the dome, which has a similar flange at the bottom. These flanges are ground together, and when greased with tallow form an air-tight joint. The inner part of the flange of the stand carries a strong moveable metal stage, accurately fitted on, which carries the knife-edges, lifting lever, a fixed mirror, and a thermometer. This stage is secured by two strong milled head screws, and can be readily removed for putting in or taking out the pendulums. The requisite attachments for exhausting the chamber, attaching a barometer or manometer, as well as a lever for giving the necessary impulse to the pendulums, are provided; the latter working through stuffing-boxes. The stand in use rests by three studs on a stout tripod with three levelling screws. The receiver and dome with the tripod weigh about fifty-two pounds.

The knife-edges, like the agates, are necessarily in two pieces, but they are practically in one by the mode of construction. A block of gun-metal 50mm. wide, 64mm. long, and 10mm. thick, to carry the knife-edges, is strongly screwed on to the platform of the stand, the opposing surfaces being ground together; the front of the block is 25mm. thick for 10mm. back, and this forms the matrix for the knife-edges; this front part of the block is divided by a recess to admit the pendulum rod, 20mm. wide, and 15mm. front to back. The knife-edges are made of the finest steel "glass hard." The mode of construction was as follows:— The steel prism, from which the knife-edges were eventually formed, was first fitted into a groove on the top of the block which was planed out to the proper form and the prism driven in as a "drift." The prism was then taken out, cut in two and hardened, then the grooves were slightly closed at the upper edges, and the pieces fixed finally in their place. The knife-edges were then ground, sharpened and polished as one piece by means of a special tool. This is a square base of cast-iron in which the gun-metal block carrying the knife-edges can be fixed precisely at right

angles to a double pair of V grooves in the base, on which a block of cast-iron carrying a grinding cylinder and running parallel to the knife-edges can be traversed as in a planing machine. The cylinder receives rapid rotation from any outside motor, while the grooved block is traversed to and fro in its grooves by hand. A means of approaching the knife-edge block towards the grinder is supplied by a fine pushing screw.

To obtain accurate horizontality of the knife-edges, a delicate level resting on agate planes similar to the pendulum cross-heads, with a light rod and bob below, forming a small pendulum, is used, and is lowered on the knife-edges exactly as the pendulums themselves are.

A second stand of cast-iron is used when swings are made at ordinary atmospheric pressures. This is formed of two A-shaped uprights joined at the top by a rectangular platform, and a heavy circular base, resting on three rounded feet. On the platform, 100mm. square, is the platform carrying the knife-edges and other arrangements as described already ; but in this case the final levelling of the knife-edge is done by levelling the platform on the stand by special levelling screws.

The coincidence apparatus consists of a stand with levelling screws carrying a rectangular metallic box, within which are an electro-magnet, armature and lever, a mirror, and a mechanical shutter. Horizontally over the metal box is mounted a telescope with a horizontal wire at its focus. In front of the box is a narrow horizontal slit, about an inch and a half below the object-glass of the telescope, and on one side of the box a circular opening admits light from a lamp, candle, or other source on to the mirror within the box, whence it is reflected on to the slit in front ; the shutter, however, occults the slits except at the instant the electro-magnet acts on the lever, when an instantaneous flash is projected through the slit. A flash would occur both at the rising and return of the lever but for the shutter (a modification of an ingenious arrangement described by Mendenhall, report cited above) which keeps the slit occulted for either the up or down stroke of the lever, as may be desired. There is a black and white scale, divided to three millimetres spaces in front of the box, with an opening for the slit above-mentioned in its centre.

The mode of observing is as follows:—The stand being placed on a solid pier of stone, brick-work, or other material, and properly levelled, it is so placed that when a pendulum is placed in it, one of the mirrors shall face the observer, who sits down from five to seven feet away, with a good steady table or tripod stand in front of him to support the coincidence apparatus, the candle or lamp for illuminating the slit, a break circuit chronometer, a telegraph key or commutator, and a portable galvanic cell. He then arranges the apparatus so that he can read his millimetre scale in front of the box as it is reflected by the mirror on the pendulum. He now connects up his coincidence apparatus with his clock or chronometer, when the electro-magnet lifts the shutter every second, and an instantaneous flash is seen by means of the telescope reflected from the mirror. He next sets the pendulum swinging through a very small arc by means of the impulse lever, when the images of the scale and slit, as seen reflected from the pendulum mirror, oscillate in a vertical direction over a distance magnified by both the telescope and the distance of the mirror from the telescope. The fixed mirror on the stand reflects a stationary image of the flash at each occurrence, while the reflection from the pendulum mirror occurs successively at all parts of the vertical arc over which it oscillates. The moment of coincidence is when the latter appears in a horizontal line with the flash reflected by the fixed mirror. The time elapsed between coincidences in the same direction of the pendulum's motion is the "coincidence period," the mean value of which in twenty-four hours is what is sought, so as to obtain the true number of vibrations made in a solar day by the several pendulums of the set, from which a mean value is deduced.

In a brief description it is undesirable to describe in detail the various adjustments and corrections, which are numerous; but what I have given here will afford some idea of the new set of half-seconds pendulums and the method of using them.